

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



ABSTRACT

Kennedy Space Center has teamed up with the Biological Computation Lab at the University of New Mexico to create a swarm of small, low-cost, autonomous robots, called Swarmies, to be used as a ground-based research platform for in-situ resource utilization missions. The behavior of the robot swarm mimics the central-place foraging strategy of ants to find and collect resources in an unknown environment and return those resources to a central site. The swarm has no prior knowledge of the environment, uses trails as a simple indirect communication strategy, and evolves a set of behavioral parameters using a genetic algorithm. The evolution of the parameters allows the swarm to maximize collection rates while adapting to new environmental conditions and to various unknown resource distributions. The goal of this research is to add new in-situ resource utilization related behaviors to the genetic algorithm and to increase the autonomy of the system.

ANTICIPATED BENEFITS

To NASA funded missions:

This research area provides several possible benefits to NASA's Science Technology Mission Directorate (STMD) Game Changing Development (GCD) Human Robotic System (HRS) projects such as Regolith Advanced Surface Systems Operations Robot (RASSOR) 2 which is under development at KSC's Swamp Works. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for autonomous navigation, path planning, and power management could improve performance and reliability of in-situ robotic mining agents such as RASSOR2. The



Two Swarmie robots are shown here searching for resources, or bar codes. NASA photo.

Table of Contents

Abstract	1
Anticipated Benefits	1
Technology Maturity	2
Management Team	2
Technology Areas	2
Detailed Description	3
U.S. Locations Working on this Project	6
Image Gallery	8
Details for Technology 1	8
Details for Technology 2	9
Details for Technology 3	10

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

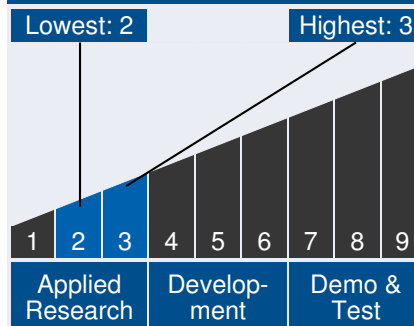
To NASA unfunded & planned missions:

This research provides potential benefit to any unfunded & planned NASA missions such as OxMiner or an Asteroid Retrieval Mission engaged in in-situ resource mining. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of in-situ robotic mining agents. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

To other government agencies:

This research provides potential benefit to other government agencies such as the Department of Defense (DOD) or Defense Advanced Research Projects Agency (DARPA) engaged in in-situ resource location and operations. Terrestrial applications include search-and-rescue, hazardous waste cleanup, land mine removal and infrastructure inspection and repair. The approach used in the software could also be adapted to search the Internet or to search large unknown data sets. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of in-situ robotic operations. The development environment, including the simulation verification environment, along with the

Technology Maturity



Management Team

Program Executive:

- John Falker

Program Manager:

- Nancy Zeitlin

Project Manager:

- Kurt Leucht

Principal Investigator:

- Kurt Leucht

Co-Investigator:

- Karl Stolleis

Technology Areas

- Robotics, Tele-Robotics & Autonomous Systems (TA 4)

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



low cost robotic platforms reduce the cost of design and development of software for these types of applications.

To the commercial space industry:

This research provides potential benefit to the commercial space industry commercial asteroid mining ventures which are proposed by Planetary Resources, Inc., Deep Space Industries, Inc. Moon Express, Astrobotics, or any entity engaged in in-situ resource location and operations. Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. The confirmation of the viable concept of operations along with the proof of concepts for the autonomous navigation, path planning, and power management improves performance and reliability of in-situ robotic operations. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications.

To the nation:

Terrestrial applications include search-and-rescue, hazardous waste cleanup, land mine removal and infrastructure inspection and repair. The approach used in the software could also be adapted to search the Internet or to search large unknown data sets. The development environment, including the simulation verification environment, along with the low cost robotic platforms reduce the cost of design and development of software for these types of applications. These technologies could make these terrestrial operations safer and more efficient via swarming robotic means.

DETAILED DESCRIPTION

As humans push further beyond the grasp of earth, robotic missions in advance of human missions will play an increasingly important role. These robotic systems will find and collect valuable resources as part of an in-situ resource utilization strategy. They will need to be highly autonomous while maintaining high task performance levels.

Kennedy Space Center has teamed up with the Biological Computation Lab at the University of New Mexico to create a swarm of small, low-cost, autonomous robots, called Swarmies, to be used as a ground-based research platform for in-situ resource utilization missions. The behavior of the robot swarm mimics the central-place foraging strategy of ants to find and collect resources in an unknown environment and return those resources to a central site. The swarm has no prior

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



knowledge of the environment, uses trails as a simple indirect communication strategy, and evolves a set of behavioral parameters using a genetic algorithm. The evolution of the parameters allows the swarm to maximize collection rates while adapting to new environmental conditions and to various unknown resource distributions.

The goal of this research is to add new in-situ resource utilization related behaviors to the genetic algorithm and to increase the autonomy of the system. Digital trails that are based on ant pheromone trails provide simple communication of resource locations between robots but they also provide some assistance with obstacle avoidance and navigation. Two newly evolved genetic algorithm parameters allow the robots to recharge their batteries autonomously without loss of robots due to insufficient charge. The genetic algorithm is able to optimize collection rates while also dealing with relatively high system error due to inexpensive and sub-optimal sensors onboard the robots. The distributed nature of the robotic swarm prevents a single point of failure and allows the system to operate even with the loss of one or more robots.

Off-planet applications of such a system include water-ice detection and mining, terrain mapping and habitat construction in advance of human explorers. Terrestrial applications include search-and-rescue, hazardous waste cleanup, land mine removal and infrastructure inspection and repair. The approach used in the software could also be adapted to search the Internet or to search large unknown data sets.

This project has helped demonstrate that in an obstacle laden environment, trails used as a simple indirect communication strategy can allow a swarm of small, low-cost robots to collect resources in an optimal manner when coupled with a genetic algorithm to evolve behaviors. This project has also helped demonstrate that an autonomous robot swarm can evolve battery charging behavior using a genetic algorithm to minimize or eliminate dead robots due to insufficient charge.

The project has been successful in meeting the original goals in simulated field trials and also in real robots. The genetic algorithm is able to evolve optimal behaviors allowing for efficient resource collection while coping with various obstacle arrangements and resource distributions. The genetic algorithm is also able to maintain a high level of fitness while incorporating autonomous recharging of the robots. It has also been demonstrated that this system is error tolerant, adaptable to different robot types, and is scalable in both environment size and numbers of robots.

All of these robot behaviors are performed in real-time with a small, low-cost onboard computer and small memory footprint. The robot platform is constructed using commercial off-the-shelf parts and

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



3D printed parts with a total cost of less than \$1,500 per robot.

A secondary goal of this project was to extend the genetic algorithm to other new and commercially available robot platforms. Another secondary goal was to use open source software frameworks to help reduce barriers and allow future researchers to more easily utilize genetic algorithms for behavior evolution in a swarm of robots. The project has been successful in meeting both of these secondary goals.

This autonomous mobile robot system is a foundation for future research into the suitability of robot swarms and evolutionary algorithms for in-situ resource utilization missions. The low-cost of this type of system removes one of the barriers typically associated with swarm operation and research. Such research should prove valuable as humans explore harsh, remote, or inaccessible locations where teleoperation is required.

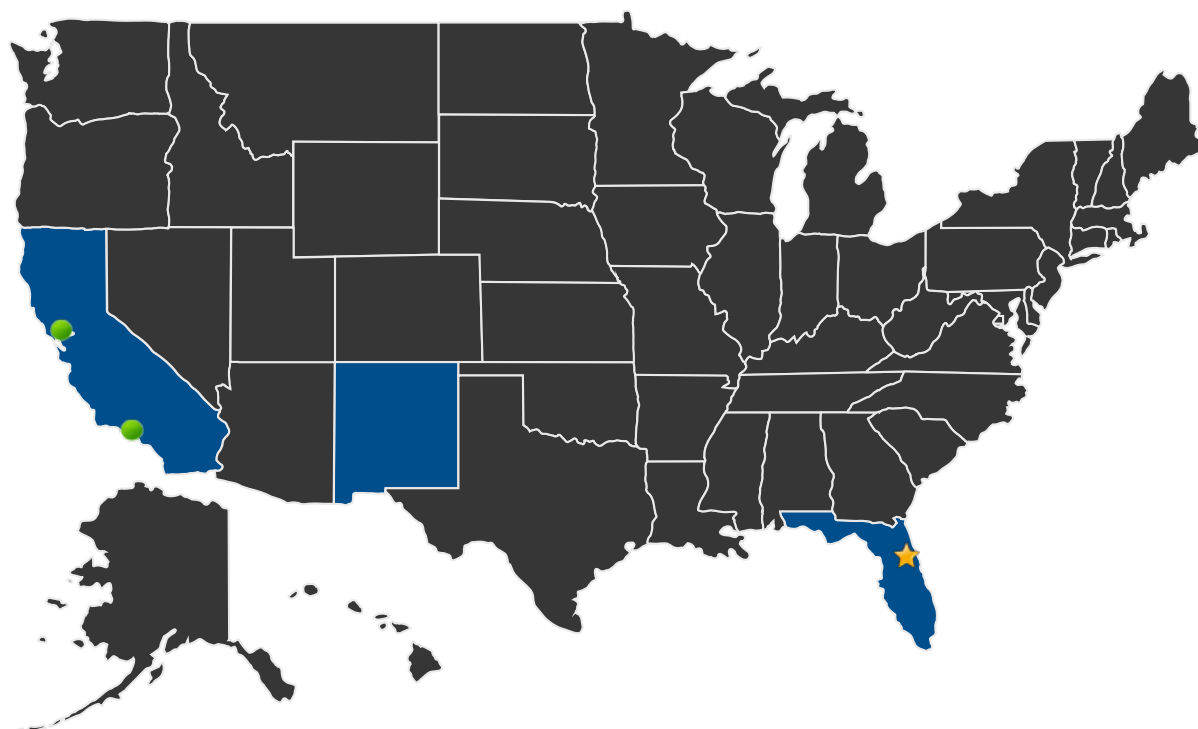
Completed Project (2014 - 2015)

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



U.S. LOCATIONS WORKING ON THIS PROJECT



■ U.S. States With Work

★ **Lead Center:**
Kennedy Space Center

● **Supporting Centers:**

- Ames Research Center
- Jet Propulsion Laboratory

Contributing Partners:

- Biological Computation Laboratory, University of New Mexico

TechPort

For more information visit techport.nasa.gov

Page 6

Some NASA technology projects are smaller (for example SBIR/STTR, NIAC and Center Innovation Fund), and will have less content than other, larger projects. Newly created projects may not yet have detailed project information.

Printed 7/24/2015

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



PROJECT LIBRARY

News Stories

- Discovery News: Swarmie Space Robots Forage Like Ants
 - (<http://news.discovery.com/tech/robotics/swarmie-space-robots-forage-like-ants-140821.htm>)
 - Engadget: NASA's Swarmies are a squad of smaller, less intelligent rovers
 - (<http://www.engadget.com/2014/08/27/nasa-swarmies/>)
 - Fast Company: These Robots Will Mine Outer Space For Water And Minerals
 - (<http://www.fastcoexist.com/3034904/these-robots-will-mine-outer-space-for-water-and-minerals>)
 - IEEE Spectrum: NASA Training Swarmie Robots for Space Mining
 - (<http://spectrum.ieee.org/autoton/robotics/military-robots/nasa-training-swarmie-robots-for-space-mining>)
 - NASA Kennedy YouTube video: Inside KSC! Feb 27, 2015
 - (<https://www.youtube.com/watch?v=mYIBabMlesE>)
 - NASA Kennedy YouTube video: Swarmies Work Through Field Tests
 - (<https://www.youtube.com/watch?v=kjSD6DWk0OM>)
 - NASA Website: Meet The Swarmies - Robotics Answer to Bugs
 - (<http://www.nasa.gov/content/meet-the-swarmies-robotics-answer-to-bugs/>)
 - NASA Website: Swarmies Shuffle Through Field Tests
 - (<http://www.nasa.gov/content/swarmies-shuffle-through-field-tests/>)
 - SPACE.com: NASA's Robot Army of Swarmies Could Explore Other Planets
 - (<http://www.space.com/26935-nasa-robot-swarmies-army-space-exploration.html>)
 - Spaceport Magazine (cover story): Robots Take World by Swarm
 - (http://issuu.com/spaceportmagazine/docs/september_spm)
 - Spaceport Magazine: Engineers seek more efficient search from Swarmies
- Continued on following page.*

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

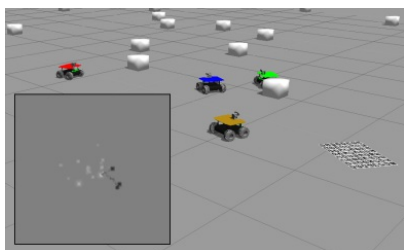
Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



News Stories (cont.)

- (http://issuu.com/spaceportmagazine/docs/spaceport_magazine____march_2015)
- WOFL FOX 35 Orlando (video segment): NASA programming robots to act like ants
 - (<http://www.myfoxorlando.com/story/26427492/nasa-programming-robots-to-act-like-ants>)

IMAGE GALLERY



This image shows a computer simulation of a swarm of robots searching for resources, or bar codes, among a field of obstacles. The inset shows a map containing obstacles in white and found resources in black.



This image shows a swarm of four robots searching for resources, or bar codes, in a NASA parking lot.

DETAILS FOR TECHNOLOGY 1

Technology Title

Autonomy

Technology Description

This technology is categorized as complex electronics software for ground support or mission operations

see detailed description

Capabilities Provided

see detailed description

Technology Areas

Other Technology Areas:

- Robotics, Tele-Robotics & Autonomous Systems (TA 4)

Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)

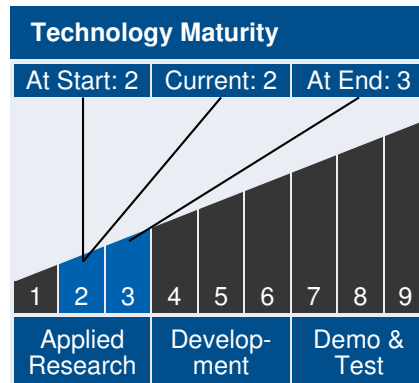


Potential Applications

see benefits descriptions

Performance Metrics

Metric	Unit	Quantity
autonomous operation	percent	100



DETAILS FOR TECHNOLOGY 2

Technology Title

Multi-Agent Coordination

Technology Description

This technology is categorized as complex electronics software for ground support or mission operations

see detailed description

Capabilities Provided

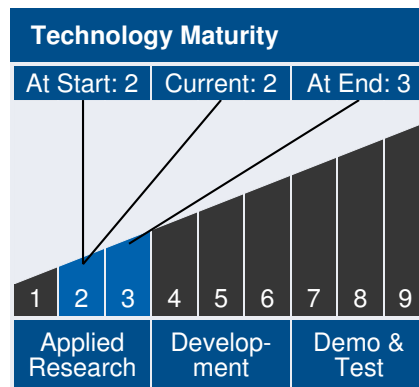
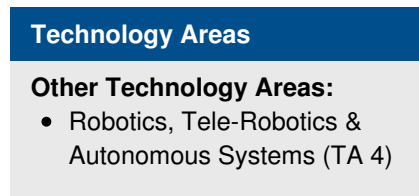
see detailed description

Potential Applications

see benefits sections

Performance Metrics

Metric	Unit	Quantity
Shares path and resource location with swarm	percent	100



Autonomous Navigation, Dynamic Path and Work Flow Planning in Multi-Agent Robotic Swarms Project

Center Innovation Fund: KSC CIF Program | Space Technology Mission Directorate (STMD)



DETAILS FOR TECHNOLOGY 3

Technology Title

Path and Motion Planning with Uncertainty

Technology Description

This technology is categorized as complex electronics software for ground support or mission operations

see details description

Capabilities Provided

see details description

Potential Applications

see benefits section

Performance Metrics

Metric	Unit	Quantity
navigates successfully to resource	percent	100

Technology Areas

Other Technology Areas:

- Robotics, Tele-Robotics & Autonomous Systems (TA 4)

Technology Maturity

